Fermi National Accelerator Laboratory

FERMILAB-Pub-78/55-EXP
7420.180

(Submitted to Phys. Rev. D)

PROBING NUCLEI WITH ANTINEUTRINOS

J. P. Berge, D. Bogert, R. Endorf, R. Hanft, J. A. Malko,
G. Moffatt, F. A. Nezrick, W. Scott, W. Smart, and J. Wolfson
Fermi National Accelerator Laboratory, Batavia, Illinois 60510 USA

and

V. V. Ammosov, A. G. Denisov, P. F. Ermolov, V. A. Gapienko,
V. I. Klyukhin, V. I. Koreshev, A. I. Mukhin, P. V. Pitukhin,
Y. G. Rjabov, E. A. Slobodyuk, and V. I. Sirotenko
Institute of High Energy Physics, Serpukhov, USSR

and

V. I. Efremenko, P. A. Gorichev, V. S. Kaftanov, V. D. Khovansky,
G. K. Kliger, V. A. Kolganov, S. P. Krutchinin, M. A. Kubantsev,
A. N. Rosanov, M. M. Savitsky, and V. G. Shevchenko
Institute of Theoretical and Experimental Physics, Moscow, USSR

and

J. Bell, C. T. Coffin, H. French, W. Louis, B. P. Roe,
R. T. Ross, A. A. Seidl, and D. Sinclair
University of Michigan, Ann Arbor, Michigan 48109 USA

June 1978

Operated by Universities Research Association Inc. under contract with the Energy Research and Development Administration

PROBING NUCLEI WITH ANTINEUTRINOS*

J. P. Berge, D. Bogert, R. Endorf,[a] R. Hanft, J. A. Malko,
G. Moffatt,[a] F. A. Nezrick, W. Scott,[b] W. Smart, and J. Wolfson
Fermi National Accelerator Laboratory
Batavia, Illinois 60510 USA

and

V. V. Ammosov, A. G. Denisov, P. F. Ermolov, V. A. Gapienko,
V. I. Klyukhin, V. I. Koreshev, A. I. Mukhin, P. V. Pitukhin,
Y. G. Rjabov, E. A. Slobodyuk, and V. I. Sirotenko
Institute of High Energy Physics
Serpukhov, USSR

and

V. I. Efremenko, P. A. Gorichev, V. S. Kaftanov, V. D. Khovansky,
G. K. Kliger, V. A. Kolganov, S. P. Krutchinin, M. A. Kubantsev,
A. N. Rosanov, M. M. Savitsky, V. G. Shevchenko
Institute of Theoretical and Experimental Physics
Moscow, USSR

and

J. Bell, C. T. Coffin, H. French,[c] W. Louis, B. P. Roe,
R. T. Ross, A. A. Seidl, and D. Sinclair
University of Michigan
Ann Arbor, Michigan 48109 USA

*Work supported in part by the U.S. Department of Energy and the National Science Foundation.

[a]Visitor: Univeristy of Cincinnati, Cincinnati, Ohio 45221.

[b]Present address: CERN, 1211 Geneva 23, Switzerland.

[c]Present address: Columbia University, New York, New York 10029.

ABSTRACT

From a sample of charged current antineutrino events in a Ne-H mixture we have obtained a subsample of events having a backward proton in the laboratory. The systematics of these backward proton events are found to be in agreement with previous results from backward proton events obtained using hadron and gamma beams.

In recent years a number of experiments have investigated backward proton production from inclusive reactions of the type

$$\alpha + A \rightarrow p + X$$

where A is a target nucleus, α is a hadron or gamma, and p is a proton emitted into the backward hemisphere in the laboratory. Backward protons cannot originate from interactions on free nucleons; therefore backward proton events permit investigation of the structure of the nucleus. Systematic investigations of experimental inclusive backward proton spectra obtained using hadron and gamma beams, as summarized by Leksin,[1] and Frankel[2] have shown that the backward proton spectra are insensitive to either the nature of the incident particle or its energy. Many different theoretical interpretations of this phenomena have been published (see for example Ref. 3). We report here backward proton production in antineutrino-neon charged current interactions. These are the first published results on backward proton production obtained from neutrino or antineutrino initiated interactions.[4]

The data come from a 74,400 picture exposure of the Fermilab 15' bubble chamber filled with a 21% atomic Ne-H mixture. The exposure was 6×10^{17} protons on target at 300 GeV using the horn focussed broad band antineutrino beam. The charged current (cc) sample was obtained by identifying the muon either by using the external muon identifier (EMI) or by applying a kinematic method based on the muon's having a high transverse momentum relative to the other particles in the event.[5] Consideration of various efficiencies and backgrounds lead to the further cc event selection requirements that the muon have momentum $P_\mu >$ 4 GeV/c and antineutrino have energy $E_{\bar{\nu}} > 10$ GeV.[6] A total of 837 antineutrino charged current events were obtained.

Tracks were identified as backward protons if all of the following criteria were satisfied:

1) The track emerged into the backward hemisphere in the laboratory.
2) The proton momentum was between 0.2 and 0.7 GeV/c.
3) The proton momentum from curvature was not inconsistent with the measured range for a proton.
4) There was no evidence for particle decay.

The selected sample contains 36 events. The momentum spectrum for the protons from this sample is shown in Fig. 1. The invariant momentum spectrum was fitted for the entire backward hemisphere ($90^\circ < \theta \leq 180^\circ$) to the form

$$\frac{E}{P^2}\frac{dN}{dP} = Ce^{-BP^2} \qquad (1)$$

to obtain the slope parameter $B = 9.5 \pm 1.9\ (\mathrm{GeV/c})^{-2}$. In Eq. (1) E and P are the proton energy and momentum respectively and C is related to the rate of backward proton production. In general the slope parameter B depends on θ. Most of the existing data is in the angular region $120^\circ < \theta < 150^\circ$. For this restricted angular range we obtain a slope parameter B' = 8.9 ± 3.1. Figure 2 shows a comparison of our value of B' to values obtained in other experiments at various energies using hadron and gamma beams incident on various targets.[7-14] Within the rather large errors our data are consistent with the conclusion that B' is independent of the type of incident particle even for an interaction initiated by a weakly interacting point-like probe.

The rate $f_{\bar{\nu}Ne}$ of backward ($\theta \geq 90^{o}$) proton charged current events relative to all antineutrino-Ne charged current events can be obtained from this data. The observed non-backward proton events are apportioned between H and Ne interactions by using the known bubble chamber mixture and the ratio $\sigma_{\bar{\nu}p}/\sigma_{\bar{\nu}n} \simeq 2.25$ obtained in this experiment.[15] We obtain $f_{\bar{\nu}Ne} = 0.07 \pm 0.01$.

The relative rate of backward proton events has been shown in hadron and gamma ray experiments to depend only on the target mass number for backward protons in a fixed angle interval.[1] Using the backward production rates measured in p-Cu and p-C reactions[11] we interpolate the rate for p-Ne reactions to be $f_{pNe} = 0.08 \pm 0.03$ for the backward proton satisfying our selection criteria. We find $f_{\bar{\nu}Ne} \simeq f_{pNe}$ which extends the observation that the rate of backward proton production is not dependent on the type of incident particle to include reactions initiated by a weakly interacting point-like probe.

We summarize the deep inelastic characteristics of the 36 backward proton events by comparing in Table I the mean values of their kinematic variables with those of the total antineutrino charged current event sample. There are large differences between the backward proton sample and total sample for $< n >$, $< TC >$, $< Q^2 >$ and $< 1 - \cos\theta_\mu >$. The differences in $< n >$ and $< TC >$ show that the backward proton events have on the average one more proton than the non-backward events. We note that the average $< Q^2 >$ and $< 1 - \cos\theta_\mu >$ are closely correlated. In a previous report[16] on antineutrino charged current interactions it was shown that $< Q^2 >$ is a function of $E_{\bar{\nu}}$. The large difference in $< Q^2 >$ cannot be attributed to the spread in center of mass energy caused by the fermi motion of the nucleons in the nucleus.

We wish to thank the members of the Neutrino Laboratory at Fermilab and the scanning, measuring and secretarial staffs at our respective laboratories for their contribution to this experiment.

REFERENCES

[1]G. A. Leksin. Invited talk given at XVII Int. Conf. on High Energy Phys., Tbilisi, 1976. Preprint ITEP - 147, 1976.

[2]S. Frankel et al., Phys. Rev. C 17, 694 (1978).

[3]L. L. Frankfurt and M. I. Strikman, Phys. Letters 69B, 93 (1977). R. D. Amado and R. M. Woloshyn, Phys. Rev. Lett., 36, 1435 (1976).

[4]For preliminary results see: "Neutrino Physics at Fermilab", by F. A. Nezrick, invited talk at the Triangle Seminar on Recent Developments in High Energy Physics, Campione D'Italia, October 3-7, 1977.

[5]This kinematic method permits recovery of events otherwise lost due to EMI geometric acceptance or technical inefficiency. For a discussion of the effectiveness of this method in supplementing the EMI see J. P. Berge et al., Proceedings of the International Neutrino Conference, Elbrus, USSR 1977.

[6] Fermilab-IHEP-ITEP-Michigan Neutrino Group, Phys. Rev. Lett. 39, 382 (1977).

[7]D. R. F. Cochran et al., Phys. Rev., D6, N11, 3085 (1972).

[8]Y. P. Antufiev et al., Sov. J. Nucl. Phys. 13, 265 (1971).

[9]K. V. Alanakyan et al., Preprint Yerevan Phys. Inst. 174 (20), (1976).

[10]Y. D. Bayukov et al., Sov. J. Nucl. Phys., 19, 648 (1974).

[11]Y. D. Bayukov et al., Sov. J. Nucl. Phys., 18, 639 (1974).

[12]K. V. Alanakyan et al., Preprint Yerevan Phys. Inst., 221 (13), (1977).

[13] T. Hayashino et al., Lettere al Nuovo Cim., 16, 71 (1976).

[14] N. Angelov et al., Sov. J. Nucl. Phys. 22, 534 (1976).

[15] "$\bar{\nu}_\mu p$ and $\bar{\nu}_\mu n$ Charged Current Interactions Unfolded from $\bar{\nu}_\mu$ Neon Events in the 15-Ft. Fermilab Bubble Chamber" - J. P. Berge et al., (to be submitted to Phys. Rev. Lett.). The value of $f_{\bar{\nu}Ne}$ is insensitive to the value of $\sigma_{\bar{\nu}p}/\sigma_{\bar{\nu}n}$.

[16] "Scaling Distributions for High Energy $\bar{\nu}$ Nucleon Scattering", J. P. Berge et al., Proceedings of XVIII International Conference on High Energy Physics, Tbilisi, USSR, 15-21 July 1976.

TABLE I

MEAN VALUE COMPARISON OF BACKWARD

PROTON EVENTS AND

CHARGED CURRENT EVENTS

Variable[a)]	Backward Proton Events	Charged Current Events
Number of Events	36	837
$< E_{\bar{\nu}} >$	25.48 ± 2.82	28.78 ± 0.71
$< P_{\mu} >$	18.10 ± 2.36	19.02 ± 0.53
$(1 - \cos\theta_{\mu})$	$(2.87 \pm 0.60) \times 10^{-3}$	$(5.96 \pm 0.31) \times 10^{-3}$
$< \nu >$	7.38 ± 1.47	9.71 ± 0.44
$< Q^2 >$	1.43 ± 0.25	3.58 ± 0.15
$< x >$	0.17 ± 0.02	0.23 ± 0.01
$< y >$	0.26 ± 0.03	0.33 ± 0.01
$< n >$	7.42 ± 0.64	6.20 ± 0.11
$< TC >$	2.14 ± 0.17	1.25 ± 0.04
$< TC_1 >$	0.81 ± 0.28	0.98 ± 0.04

a) $x = Q^2/2M_p\nu$, $y = \nu/E_{\bar{\nu}}$, $\nu = E_{\bar{\nu}} - E_{\mu}$, $E_{\bar{\nu}}$ is the antineutrino energy; E_{μ}, P_{μ} and θ_{μ} are the muon laboratory energy, momentum and scattering angle; Q^2 is the absolute value of the momentum transfer between the $\bar{\nu}$ and muon; n = number of prongs (including identified neutrals); TC = total charge (sum of identified positive tracks minus identified negative tracks); TC_1 = total charge as above minus protons with momentum < 1 GeV/c.

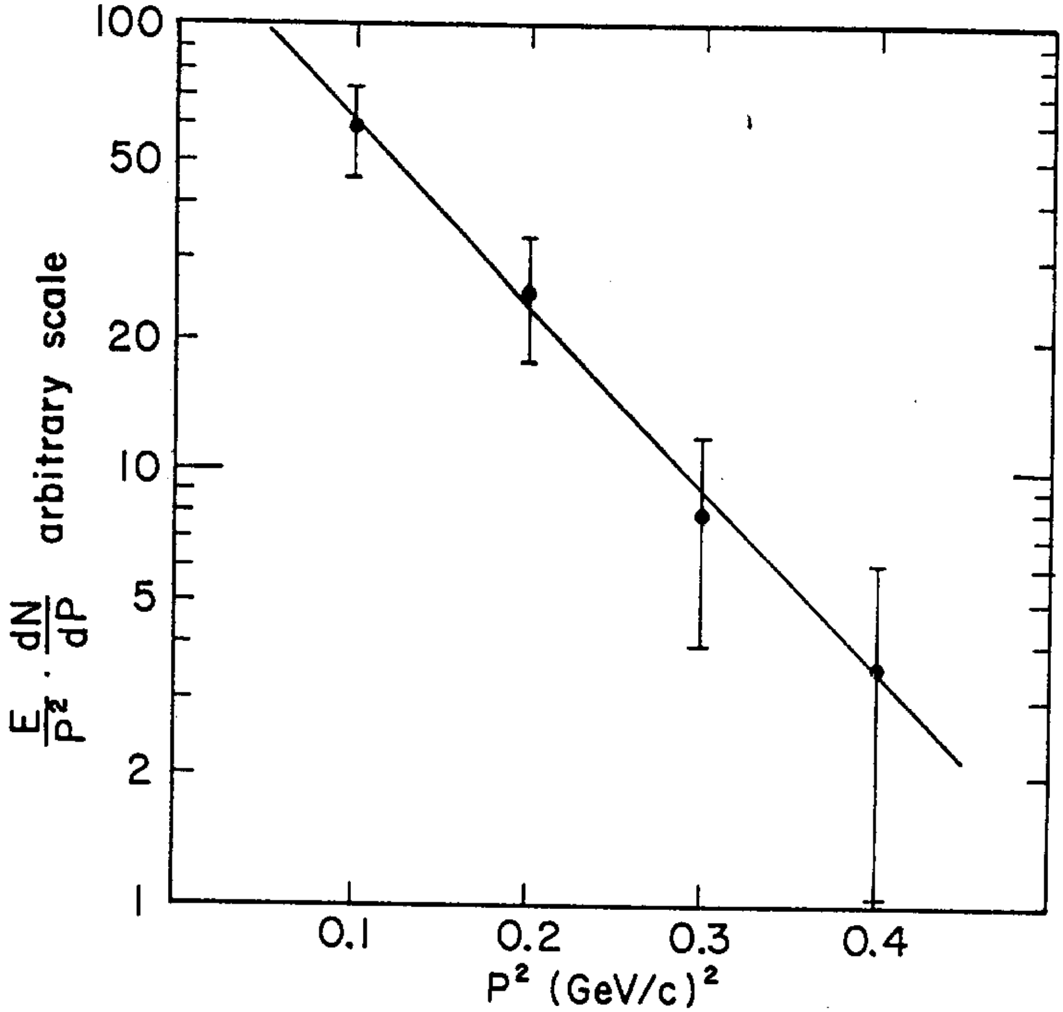

Figure 1

Distribution of proton laboratory momentum (P) for the 36 backward proton events. The solid line is a fit to $E/P^2\ dN/dP = Ce^{-BP^2}$.

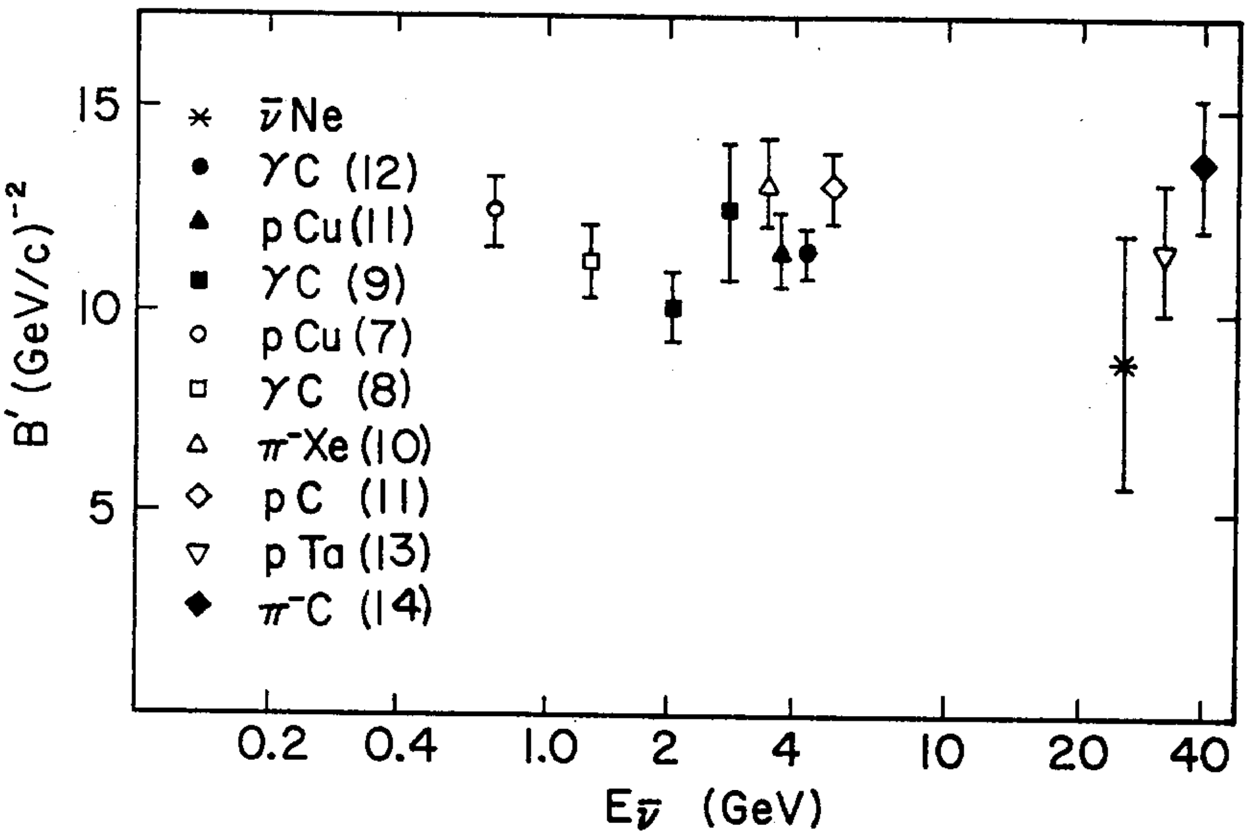

Figure 2

Comparison of the parameter B' obtained in this experiment to values obtained in other experiments at various energies using hadron and gamma beams incident on various targets.